

IN-SITU PLASMA ASH/TREATMENT AFTER VIA ETCH OF LOW-K FILMS FOR POISON-FREE DUAL DAMASCENE TRENCH PATTERNING

CROSS-REFERENCE TO RELATED APPLICATIONS

5 The following co-pending applications are related and hereby incorporated by reference:

| <u>Serial No.</u> | <u>Filing Date</u> | <u>Inventors</u> |
|---------------------|--------------------|---------------------|
| 60/247,562 | 11/02/2000 | Jiang et al. |
| 60/250,241 | 11/30/2000 | Eissa et al . |
| 10 60/255,715 | 12/14/2000 | Kirkpatrick et al . |
| 60/255,714 | 12/14/2000 | Kirkpatrick et al. |

FIELD OF THE INVENTION

15 The invention is generally related to the field of forming interconnect layers in a semiconductor device and more specifically to patterning low-k dielectric films.

BACKGROUND OF THE INVENTION

20 As the density of semiconductor devices increases and the size of circuit elements becomes smaller to achieve better performance, the resistance capacitance (RC) delay time in back-end-of-line (BEOL) increases and dominates the circuit performance. To reduce the RC delay time at BEOL, the demands on interconnect layers for connecting the semiconductor devices to each other also
25 increase. Therefore, there is a desire to switch from the traditional aluminum metal interconnects to copper interconnects and from traditional silicon-dioxide-based dielectrics to low-k dielectrics, such as organo-silicate glass (OSG). Semiconductor fabrication processes for working with the copper interconnects and newer low-k dielectrics are still needed.

As compared to the traditional subtractive plasma dry etching of aluminum, suitable copper etches for a semiconductor fabrication environment are not readily available. To overcome the copper etch problem, damascene processes have been developed. In a damascene process, the IMD (intra-metal dielectric) is formed first.

5 The IMD is then patterned and etched to form trenches for the interconnect lines. If connection vias have not already been formed, a dual damascene process may be used. In a via-first dual damascene process, an ILD (interlevel dielectric) is deposited first, followed by an IMD deposition. An IMD etch-stop layer, such as SiN, can be optionally used in between IMD and ILD. A via is patterned and etched
10 through the IMD and ILD for connection to lower interconnect levels. Then a trench is patterned and etched in the IMD. A barrier layer and a copper seed layer are then deposited over the structure. The barrier layer is typically tantalum nitride or some other binary transition metal nitride. The copper layer is electrochemically deposited (ECD) using the seed layer over the entire structure. The copper is then
15 chemically-mechanically polished (CMP'd) to remove the copper from over the IMD, leaving copper interconnect lines and vias. A metal etch is thereby avoided.

When low-k dielectrics such as OSG are used for the IMD and ILD, a problem known as resist poisoning occurs. Resist poisoning occurs during a
20 patterning step such as via pattern or trench pattern. It is a result of the interaction between a DUV (deep ultra-violet) resist and low-k films. Resist poisoning causes poor resist sidewall profiles, resist scumming, large CD variations, and requires a large resist exposure dose. Furthermore, the required resist exposure dose to achieve the target CD becomes too high and varies with film aging. A process to
25 reduce or eliminate resist poisoning in low-k dielectrics is therefore desired.

SUMMARY OF THE INVENTION

5 The invention is an in-situ plasma treatment for low-k films that improves patterning. After via etch, the wafer with a low-k film is treated with a plasma, such as an O₂ plasma, to eliminate or significantly reduce resist poisoning. The plasma treatment may be performed in the same chamber or a separate chamber if the transfer is performed under vacuum. After plasma treatment, the trench patterning is performed.

10 An advantage of the invention is providing a treatment to reduce or eliminate resist poisoning of low-k dielectric films.

15 This and other advantages will be apparent to those of ordinary skill in the art having reference to the specification in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

- 5 FIGs. 1A-1F are cross-sectional diagrams of a process for forming metal interconnects according to the embodiments of the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The invention will now be described in conjunction with dual damascene copper interconnect process. It will be apparent to those of ordinary skill in the art that the benefits of the invention may be applied generally to patterning of low-k ($k < 3.0$) and ultra-low-k ($k < 2.5$) films.

In order to form the copper interconnects using a dual damascene process, the interlevel dielectric (ILD 102) and intra-metal dielectric (IMD 104) of FIG. 1A are patterned and etched to form trenches in IMD 104 and vias in ILD 102. When low-k or ultra low-k materials are used for the ILD and IMD, an interaction between the resist and the low-k materials causes resist poisoning. The cause of resist poisoning is believed to be the interaction between the DUV resist and nitrogen-containing reagents from the low-k films. Possible sources of nitrogen include: the low-k film, the dielectric cap and optional IMD etch-stop layers (e.g., SiN) and/or chemistries used in the deposition of these films, N_2 in the clean (ash) process, N_2 in the etch chemistry, and the photoresist itself.

In order to reduce or eliminate the resist poisoning, an in-situ plasma ash and treatment is performed. In the preferred embodiment, an O_2 plasma is used. Alternatively, other plasma chemistries such as H_2 , H_2O , H_2O_2 , O_3 , CO , CO_2 , SO_2 , etc. may be used with or without gas additives like Ar or He.

As an example, the following O_2 plasma process may be used in a TEL DRM plasma reactor with dual chambers. Organo-silicate glass (OSG) is used as the ILD/IMD. After via etch in one chamber, the wafer is transferred immediately (under vacuum) to the other chamber for the following ash/treatment process:

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|-----------|---------|
| Time: | 40 sec. |
| Pressure: | 150mT |

Power: 400W
Flow: 400 sccm O₂
Chuck Temp.: 40°C

Using the above process parameters, a resist ash rate of 9000 Å/min can be achieved. The OSG etch rate is 110Å/min.

The plasma process conditions are designed to strip off the resist and remove nitrogen adsorbed on the resist and via sidewalls as well as in the dielectric film. Therefore, resist poisoning is prevented. The duration of the plasma treatment is highly dependent on the amount of nitrogen from the various nitrogen sources to be removed. For example, if a SiN capping layer is used, the duration of the plasma process may need to be increased.

An embodiment of the invention will now be discussed with reference to FIGs. 1A-1F. A semiconductor body 100 is processed through the formation of a first interconnect layer. Semiconductor body 100 typically comprises a silicon substrate having transistors and other elements formed therein. Copper interconnect level may be the first or any subsequent metal interconnect level of the semiconductor device 120.

An etchstop layer 101 is deposited over the first interconnect layer. An ILD 102 is formed over etchstop layer 101. IMD 104 is formed over ILD 102. A trench etchstop layer (not shown) may optionally be placed between ILD 102 and IMD 104. ILD 102 and IMD 104 comprise low-k or ultra low-k dielectrics, such as organo-silicate glass (OSG), inorganic films and organic films. In the preferred embodiment, ILD 102 and IMD 104 comprise the same material. However, ILD 102 and IMD 104 may alternatively comprise different materials. A capping layer 105 may be formed over IMD 104 if desired. In the preferred embodiment, the capping layer comprises silicon carbide (e.g., BLok from Applied Materials). Alternatively, a silicon oxide, silicon nitride, silicon oxynitride (SiON), Si-rich

nitride (SRN), or no capping layer may be used.

Referring to FIG. 1B, the via pattern 130 is formed over capping layer 105. The via 106 is then etched through IMD 104 and ILD 102, as shown in FIG. 1C.

After the via etch, an in-situ plasma ash/treatment is performed according to the invention. The plasma treatment may be performed in the same chamber as the via etch or in a separate chamber of the same tool. For example, the TEL DRM plasma reactor is available with dual chambers. One chamber may be used for the via etch, while the other chamber is used for the plasma ash/treatment. If a separate chamber is used, the wafers should be transferred under vacuum. Other RIE (reactive ion etching) etcher/ashers may alternatively be used.

An O₂ plasma is preferably used for the plasma treatment. However, other chemistries, such as those involving H₂, H₂O, H₂O₂, O₃, CO, CO₂, or SO₂, etc. with or without inert gases like Ar or He, may alternatively be used. Analysis of RIE O₂ plasma treated low-k films revealed some carbon depletion, but no significant damage to the OSG film. Care should be taken to limit oxidation so as not to damage the low-k film.

An advantage of the invention is improved throughput. The plasma treatment removes (ashes) the resist of via pattern 130 and functions as a wafer clean in addition to eliminating resist poisoning. Thus, the in-situ process reduces the overall via etch and clean time.

The plasma treatment should be performed immediately after the via etch. An advantage of the invention is that the source of poisoning (e.g., N that is adsorbed on the resist and via sidewall) is removed immediately after the etch.

This minimizes the time that the wafers are exposed to the poisoning source and also prevents any poisoning reactions that may be enhanced by moisture exposure.

In order to protect the bottom of via 106 during the subsequent trench etch, via 106 may be partially or completely filled. For example, an organic BARC (bottom anti-reflection coating) 107 may be deposited over the structure and etched back such that BARC material remains only in the via 106.

Next, a trench pattern 132 may be formed over IMD 104, as shown in FIG. 1D. An in-situ plasma ash/treatment after via etch reduces or eliminates the poisoning problem at trench pattern. With a SiO₂ capping layer 105 or no capping layer, both in-situ and ex-situ O₂ plasma ash show no resist poisoning. When a SiC capping layer 105 is used, a flood exposure after via clean shows a clear difference among in-situ O₂ plasma ash, ex-situ O₂ plasma ash and a H₂/Ar plasma ash. The exposure energy required to clear resist inside a via is the lowest for the wafer with in-situ O₂ plasma ash, indicating the most robustness for fighting poisoning.

After trench pattern, a trench 108 is etched in IMD 104, as shown in FIG. 1E. Trench pattern 132 and BARC 107 are then removed. The capping layer 105 and etchstop layer 101 are removed next during an etchstop etch. Copper interconnect structures will subsequently be formed in trench 108 and via 106.

Barrier layer 110 is deposited over IMD 104 including in trench 108 and via 106. Barrier layer 110 functions to prevent copper diffusion into the ILD and IMD layers. Suitable barrier materials such as Ta/TaN are known in the art. A seed copper layer is then deposited over barrier layer 110.

Electrochemical deposition (ECD) may then be used to deposit copper layer 124. Various copper ECD processes are known in the art. In one example, a 3-step process is used. After placing the wafer in the plating solution, a current of approximately 0.75 Amps is passed through the seed layer for a time on the order of 15 seconds. The current is then increased to around 3 Amps for approximately 60 seconds. Final plating occurs at a current of about 7.5Amps with the duration determined by the final desired thickness. A quick spin-rinse dry (SRD) is performed in the plating cell above the plating solution. The wafer is then transferred to the SRD cell and a post-ECD SRD is used to clean the plating residue.

After copper ECD, the copper 124 and barrier 110 are chemically mechanically polished (CMP) to remove the material from above IMD 104. The resulting structure is shown in FIG. 1F. Next level ILD and IMD may be deposited and processing may then continue to form additional metal interconnect levels and package the device.

As a result of the plasma treatment according to the invention, the DUV pattern energy required to achieve the target CD (critical dimension) is reduced. In one experiment, a via was patterned on a wafer having a 1000 Å SiC cap. The IMD comprised OSG. The O₂ plasma process conditions were: pressure-45mT, power-400W, O₂ flow rate-400 sccm, and a chuck temperature of 40°C. The pattern energies required to achieve the target CD were as shown below:

| | |
|--|------------------------|
| OSG films with H ₂ /Ar ash: | ~35 mJ/cm ² |
| OSG films with ex-situ O ₂ ash: | ~30 mJ/cm ² |
| OSG films with in-situ O ₂ ash: | ~25 mJ/cm ² |

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well

as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.